UXO DETECTION USING AN INTEGRATED NQR/EMI SYSTEM

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Abstract

Nuclear quadrupole resonance (NQR) provides a means for detecting explosives contained in non-metallic cases. In contrast to metal detectors and ground-penetrating radar (GPR), NQR detection systems do not produce false alarms due to shrapnel, spent rounds, tin cans, nails, and other metallic clutter. In addition, NQR detection systems provide both spatial localization and chemical identification of explosives. While NQR is a promising technology for the detection of minimal metal landmines, the application to UXO detection is severely limited because metallic cases will shield the explosives from the NQR system. However, it has been demonstrated that an NQR system can be modified to detect metallic materials using electromagnetic induction. We propose that electromagnetic induction (EMI), which enables both detection and discrimination of metallic materials, can also be implemented using an NQR system. This paper considers the challenges and limitations in designing a single system that provides both NQR and EMI detection capability.

Background

The NQR process induces the nuclei of specific atoms to store RF energy for a short time and then rebroadcast the RF energy to a detector. The precise radio frequency at which this occurs yields information on the presence of the atom, and how it is bonded to the surrounding molecular structure.

NQR spectroscopy was developed in the late 1940s and early 1950s as an outgrowth of the discovery of nuclear magnetic resonance (NMR)[1]. In contrast to NMR, less interest was shown in the development of experimental techniques for NQR. This lack of interest was probably due to two factors. First, because hydrogen nuclei admit an NMR signal but not an NQR signal, NMR has received greater attention and is widely used in analytical chemistry. Second, in comparison to most NMR experiments, the signals obtained in NQR spectroscopy are significantly smaller in magnitude. Today, NQR is used primarily to determine the crystallographic structure of specific compounds. All but a few commercially produced units are designed for this purpose.

Renewed interest in NQR for detection of explosives stems from work conducted at Brown University during the late 1960s and early 1970s. Marino studied the bonding of nitrogen by NQR using continuous-wave spectroscopy[2]. Several years later, Petersen developed instrumentation for pulsed NQR spectroscopy and studied the nitrogen-14 spectrum and relaxation in sodium nitrite[3].

During the Vietnam conflict, the North Vietnamese forces would recycle American munitions as satchel charges and liberally seed roadways with both satchel charges and decoys. Metal detectors were unable to identify the satchels loaded with explosives. Hirschfeld proposed that NQR might provide a means for directly detecting the explosive material, and therefore provide a means for discriminating between the explosive satchels and decoys[4]. Marino was the first to detect NQR signals in RDX[5], and later presented a review paper on NQR spectroscopy of explosive materials that included TNT, PETN, RDX, and HMX[6]. In each of these compounds the NQR signal is generated by ^{14}N nuclei.

Nearly two decades later, researchers at NRL developed NQR technology for civilian aviation security. Buess[7,8] showed that a pulsed NQR spectrometer can detect sub-kilogram quantities of explosive. To scan a person without depositing substantial RF power into their body, a meanderline surface coil was used. The magnetic field produced by the meanderline coil falls off rapidly over a short region so that the search is localized to within a few inches of the coil.

Buess[9] also investigated the design of coils to search a large volume (300 L). In conventional NQR spectroscopy methods, the applied RF power must increase linearly with the coil size, and hence the search region. The linear scaling results in RF power levels that are not practical. Buess recognized that the RF power level need only increase as the square root of the search volume to maintain a constant signal-to-noise ratio.

At least two commercial NQR detection systems have been developed. Quantum Magnetics in San Diego, California, and British Technology Group (BTG) in conjunction with King's College, London, England, have produced NQR detection systems for narcotics and explosives detection in airline baggage. Recently, the SEE Corporation in Perth, Australia, has also started work on NQR detection systems for aviation, landmine, and postal applications. With funding from DARPA, Quantum Magnetics is conducting field trials of an NQR system for detection of mines containing RDX.

Researchers in the former Soviet Union began investigating NQR as means to detect AT landmines during the war in Afghanistan. Grechishkin, at the Kaliningrad State University in Russia, developed an NQR detection system that could sweep a one-square meter area in ten seconds with a detection rate over ninety percent for mines buried within 10 cm of the surface[10,11]. His group also demonstrated that the NQR system could detect 2.5 kg of RDX buried 35 cm underground using a RF power level of 1 kW[12]. Recently, Grechishkin described a method for determining the burial depth based on finding the optimal frequency offset in a RF pulse sequence[13].

Based on this prior research, NQR landmine detection systems have several significant advantages compared to other technologies such as metal detectors and ground-penetrating radar.

Remote, Noninvasive Measurement - Any NQR detection method is noninvasive because a magnetic field is used to probe for explosives. In landmine detection, a coil similar to that employed in inductive metal detectors is used.

Detection of Minimal Metal Landmines - NQR is well suited for detecting landmines with nonmetallic enclosures because it detects the explosive material and not the surrounding case.

Discrimination of Metal Clutter - The RF pulse sequences used in NQR detectors can be designed to reject extraneous signals induced by metallic clutter. As a result, in contrast with metal detectors, NQR detection systems do not produce false alarms induced by shrapnel, spent rounds, tin cans, nails and other metallic items.

Explosive Identification - The fact that the resonance lines are uniquely determined by the explosive compound enables NQR to distinguish between different types of explosives. As an example, for TNT and PETN, the transition frequencies range from 700 kHz to 900 kHz. In contrast, for RDX, resonance lines are located near 3.41 MHz and 5.19 MHz.

NQR detection methods require that the nuclei be exposed to a time-varying magnetic field whose frequency is typically several hundred kilohertz or higher. At these frequencies, metal casings shield explosives from the applied magnetic field. This fact prevents NQR from directly detecting explosives surrounded by metal. On the other hand, the RF pulses generated by the NQR system will induce eddy currents in the metallic casing. This suggests that NQR systems can also detect metal using electromagnetic induction (EMI).

An Integrated NQR/EMI System

The application of EMI to UXO detection has been well studied and is an area of active research. Recently Hibbs[14] showed that an NQR system can be easily modified to detect the secondary magnetic field induced in the metallic case of a landmine. A RF source of fixed frequency is gated to produce a train of magnetic field pulses that induce eddy currents in the metallic case. The induced currents generate a secondary magnetic field that is then detected. The performance of the modified NQR system is comparable to that of the Schiebel AN-19/2 metal detector, which is currently used by U.S military forces. As with other inductive metal detectors, however, the modified NQR system is not capable of distinguishing metal clutter from ordnance.

Recently, Won[15] proposed the concept of electromagnetic induction spectroscopy (EMIS) which differs from conventional inductive metal detection in two important respects. First, a phase-sensitive detector resolves the received signal into in-phase and quadrature components. Second, the secondary magnetic field is measured in a broad spectrum by sweeping the frequency of the applied magnetic field. Viewed in the frequency domain, the magnitude of the in-phase and quadrature signals provides a spectral fingerprint. Of particular significance, is the fact that this method can discriminate between different types of metals, thereby picking out ordnance from metal clutter.

We propose to incorporate EMI into an NQR detection system, and are currently evaluating the feasibility of such an integrated system. NQR systems designed to detect TNT and RDX are capable of generating magnetic fields with frequencies at about 800 kHz and 3.41 MHz. In contrast, Won collected data over a frequency range spanning from 270 Hz to 23,970 Hz. In this frequency band there is considerable variation in the magnitude of the in-phase and quadrature components of the received signals. Data at higher frequencies are not yet available. And so a key question that must be answered is whether or not useful EMI data can be obtained in the narrow frequency bands used in NQR detection systems. There are also questions regarding the integrated design. Although not expected to present difficult challenges, they still must be addressed. For example, small metallic objects such as firing pins produce a secondary field that decays with a time constant of approximately 10 μs. In comparison, the relaxation time of NQR signal obtained from RDX is more than an order of magnitude larger. This factor must be taking into account when designing the tuned NQR search coil and receiver system. If successful, the integrated NQR/EMI system will provide an effective means of detecting both minimal metal landmines and UXO. This system would be capable of detecting, discriminating, and classifying both explosives and metals.

Biography

Jeffrey Schiano assistant professor in the Department of Electrical Engineering at Penn State University, University Park. He received his Bachelor's degree from Carnegie-Mellon University, and his Master's and Doctoral degrees from the University of Illinois at Urbana-Champaign, all in electrical engineering. His primary research focus is on the application of feedback control concepts to quantum mechanical processes, in particular, nuclear quadrupole resonance and magnetic resonance imaging.

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